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Understanding macrobenthos and ecotoxicology through experiential learning: A shared classroom journey

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Abstract

This paper synthesizes the shared experiences of students and mentor during a practical class on ecotoxicology and macrobenthos analysis conducted at the Department of Biology, Universiti Putra Malaysia. The session combined three linked components: collection of surface sediments from a polluted drainage, short behavioural assays with the catfish *Clarias* sp. under contrasting pH conditions, and microscopic identification of benthic organisms sorted from sieved sediments. Students encountered tolerant taxa such as oligochaetes, chironomid larvae, odonate nymphs, and freshwater snails, and related their presence to habitat quality and contaminant exposure. Reflections recorded immediately after the class documented excitement, surprise, and a growing ability to frame observations as evidence. Learners reported that touching the sediment, smelling the water, and watching fish opercular movements made abstract concepts concrete and memorable. The objective of this paper is to evaluate how a tightly integrated field-to-laboratory activity fosters conceptual understanding, scientific empathy, and confidence in interpreting ecological signals from disturbed urban habitats. We analyze student vignettes alongside photographic evidence to show how cooperative sampling, rapid identification, and simple bioassays create a coherent pathway from observation to inference. The findings suggest that experiential practice, when guided by clear prompts and on-the-spot mentoring, strengthens the link between environmental processes and their biological indicators, encourages collaborative reasoning, and motivates further inquiry. The paper offers a concise model that other mentors can adapt to help students connect ecotoxicological theory with lived phenomena and to cultivate the habits of careful seeing, patient interpretation, and ethical attention to organisms in degraded environments.

Keywords Ecotoxicology, macrobenthos, experiential learning, bioindicator, environmental education

1. Introduction

Ecotoxicology integrates scientific observation with sensory learning and aligns naturally with experiential and emancipatory approaches to education [1]. In this papers, students engaged with macrobenthic organisms as living indicators of pollution through a blended sequence of field sampling and laboratory analysis, reflecting best practices in interactive and technology-supported experiential learning [2]. The design echoes insights from virtual and global experiential frameworks that emphasize participation, reflection, and teamwork to deepen conceptual understanding [3]. Because degraded sites often cue learning through multiple senses, we foregrounded olfactory and tactile observation as part of the pedagogical method [4], and we treated the campus drainage and surrounding built environment as an accessible urban field classroom [5]. Together these elements align with the tradition of experiential learning for sustainability that links observation to action-oriented inquiry [6]. Instead of relying solely on lectures, students carried out sediment sampling, a short behavioural assay in catfish, and microscopic examination of benthic taxa, enabling them to directly perceive how pollution shapes ecological systems. The practical session unfolded in a spirit of curiosity and collaboration as students discussed, laughed, and shared their surprise at life thriving in degraded environments; the process was both analytical and deeply experiential, requiring sight, touch, smell, and interpretation [1, 4].

The objective of this paper is to document and analyze an ecotoxicology practical that integrates field and laboratory activities to cultivate experiential understanding, sensory-based observation, and collaborative reflection, drawing on contemporary scholarship in transformative learning, blended and interactive platforms, global experiential teamwork, sensory pedagogy, urban field classrooms, and sustainability-oriented action research [1-6].

2. Field sampling

Figure 1 illustrates standardized collection of surficial sediments from the 0–10 cm layer into labelled bags, a depth window widely used to capture recent depositional material where contaminants, organic fines, and bioavailable fractions accumulate; thereby representing the habitat actually experienced by macrobenthos [7, 8]. Choosing a shallow, well-defined stratum also limits vertical mixing artefacts and aligns with quantitative tools designed for benthic invertebrate work at the mud–water interface [9]. Because grain size governs oxygen penetration and pollutant retention, field sampling that preserves textural integrity is essential for interpreting the presence of tolerant taxa such as tubificid oligochaetes and chironomid larvae; pairing collection with subsequent textural assessment strengthens ecological inference [10]. In dynamic settings, near-bed processes and vessel or flow-driven resuspension can redistribute fine, contaminated particles, so documenting the sampling context and hydrodynamic conditions helps explain patchiness in macroinvertebrate distributions [11, 12].

Figure 1 Field sampling of surface sediments from a polluted drainage channel conducted by students at the Department of Biology, Universiti Putra Malaysia. All photos were taken on 12 November 2025 and are not manipulated by any AI applications.

Operationally, the sequence shown namely gloves, scoops, immediate labelling, and secure containers, that prioritizes safety, traceability, and sample integrity for downstream laboratory work [7, 8]. Such careful handling supports a tight link between field evidence and lab-based ecological interpretation, where sorted surficial fauna and sediment properties are analyzed together to read pollution signals. As comparative studies demonstrate, even simple field protocols, when executed consistently and paired with appropriate lab procedures, recover rich invertebrate assemblages and reveal stress gradients in resource-limited systems [13]. The teamwork visible in Figure 1, shared roles in scooping, bagging, and metadata recording that embeds quality assurance into the sampling act itself, laying a reliable foundation for macrobenthic assessment.

3. Understanding benthic organisms through sediment sieving in polluted drainage environments

Figure 2 captures the pivotal transition from habitat to evidence. In panel A, students crouch over the drain, rinsing sediments through a hand sieve to concentrate macrobenthos while minimizing fine silt that obscures organisms; the dark slurry falls away while worms, larvae, and small snails remain visible for collection. In panel B, the team gathers around the fresh catch as the mentor cross-checks features against a field guide, turning raw material into named taxa and quick hypotheses about tolerance and habitat quality. The sequence shows efficient field workflow namely sieving, rinsing, transferring to trays, and rapid verification, and the cooperative rhythm of inquiry where technique, dialogue, and bioindicator interpretation unfold at the sampling site.

Figure 2 Sequential stages of field-based macrobenthos sampling and identification conducted by students and mentor. (A) Students sieving surface sediments from a visibly polluted drainage channel to isolate macrobenthos using a hand sieve. (B) Careful inspection and sorting of the sieved material to isolate living organisms such as worms, larvae, and snails. (C) Immediate, on-site discussion of the sieved catch with the mentor using field guides to verify taxa and link habitat conditions to bioindicator interpretation. The integrated workflow illustrates experiential learning that connects sediment handling, organism recognition, and ecological reasoning. All photos were taken on 12 November 2025 during the same session and are not manipulated by any AI applications.

Figure 2 demonstrates experiential learning in motion, where theory and practice intersect through direct engagement with the environment. The sieving of sediments (Figure 2A and 2B) embodies the essence of active, sensory participation, allowing students to perceive ecological data through touch and sight rather than abstraction. Such embodied practices are central to experiential education, which transforms observation into understanding by engaging learners cognitively and physically [1, 3]. The subsequent discussion and field identification (Figure 2C) represent reflective dialogue, which is a crucial element in consolidating experiential knowledge [2, 6]. These interactions not only enhance students' scientific reasoning but also foster teamwork, empathy, and a shared environmental consciousness [14, 15]. Figure 2, therefore, visualizes the pedagogical cycle of experience, reflection, and conceptualization that underpins transformative learning in ecotoxicology and environmental science [16, 17].

4. Macrobenthic assemblages as biological indicators of pollution in drainage sediments

Figure 3 summarizes the benthic assemblage recovered from the drainage and highlights three pollution-tolerant bioindicator groups. In panel A, two petri dishes display the mixed catch sorted from surface sediments, including red oligochaetes, insect larvae, and small gastropods. Panel B shows an odonate larva with a sturdy, segmented body and raptorial labium, useful for linking habitat structure to predation ecology. Panel C depicts a bright red tubificid oligochaete whose hemoglobin-rich tissues enable persistence in low-oxygen, high-organic sediments. Together, these images illustrate how routine field sorting yields diagnostic taxa that translate habitat condition into interpretable biological signals.

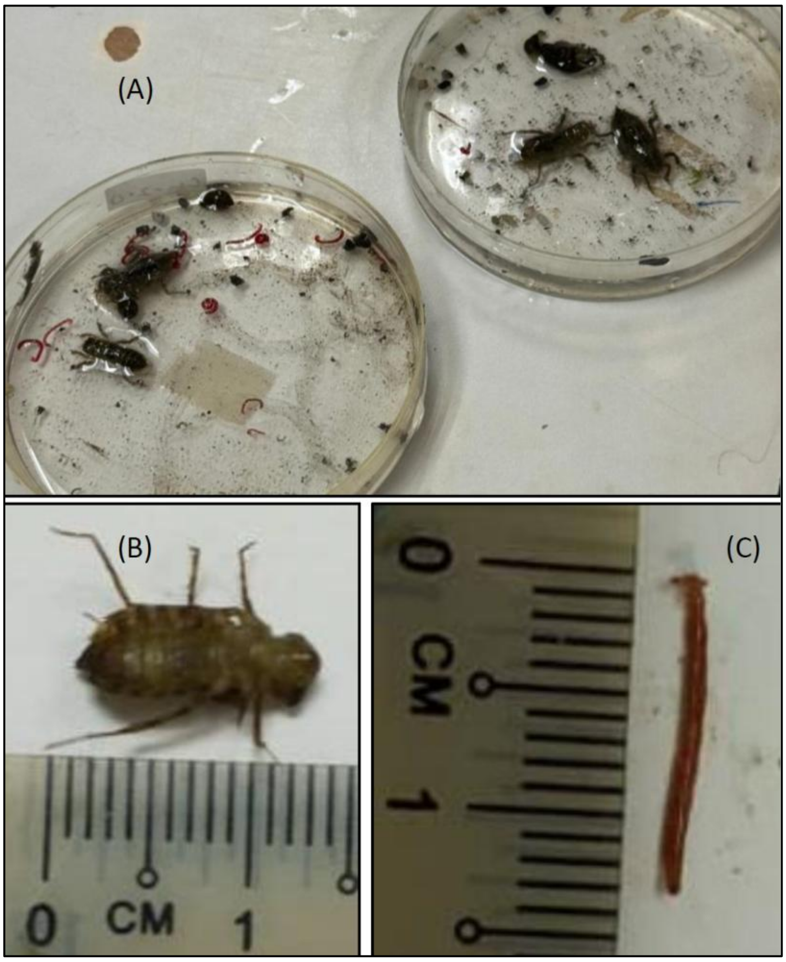

Figure 3 Representative macrobenthic organisms collected from the polluted drainage system during the ecotoxicology practical. (A) Petri dishes containing assorted benthic fauna, including red aquatic worms, insect larvae, and snails, sorted from sediment samples. (B) Odonate larva showing a robust chitinous body adapted to low-oxygen environments. (C) Red oligochaete worm (family Tubificidae) commonly found in organically enriched or low-dissolved oxygen habitats. These specimens collectively represent key bioindicator taxa used to assess sediment contamination and ecological resilience in degraded aquatic systems. All photos were taken on 12 November 2025 during the same session and are not manipulated by any AI applications.

Figure 3 shows a benthic assemblage typical of organically enriched, low-oxygen drainage sediments: hemoglobin-rich tubificid oligochaetes, hardy odonate larvae. High densities of oligochaetes are a classic indicator of sediment enrichment and hypoxia because their physiology and burrowing behavior allow persistence where sensitive taxa decline [18, 19]. Odonate larvae tolerate a wide range of physicochemical conditions and often persist in urban channels where flow is variable and fine particles accumulate, providing a robust link between habitat structure and biological response [20, 21]. *M. tuberculata* is frequently recorded in disturbed or nutrient-rich freshwater settings, where it exploits organic deposits and tolerates fluctuations in water quality [22, 23]. Together, these taxa translate the visibly polluted sediments into a coherent biological signal of organic loading and oxygen stress consistent with standard biomonitoring interpretations [24].

5. Behavioural and physiological responses of catfish to acute PH stress: Observation of mucus secretion and erratic movements under acidic conditions

Catfish (*Clarias* sp.) is native to Southeast Asia and is commonly used in laboratory bioassays and ecotoxicological studies due to its tolerance to low oxygen and poor water quality [25]. From Figure 4, the catfish in acidic water (pH 2.24 in A) began showing erratic swimming behaviour within 10 minutes, accompanied by mucus secretion and bubble formation near the gill region, indicating physiological stress and impaired respiration. In contrast, the catfish maintained in near-neutral water (pH 6.20 in B) exhibited normal orientation and steady opercular movements. The visual comparison demonstrates the clear behavioural and physiological differences between acid-stressed and control conditions, emphasizing the sensitivity of aquatic organisms to pH fluctuations and the pedagogical value of real-time observation in ecotoxicology experiments.

Figure 4 Behavioural responses of catfish (*Clarias* sp.) exposed to contrasting pH environments during a short-term (10 minutes) experiment. (A) Catfish in acidic water (pH 2.24) showed visible mucus secretion and bubble formation from the gills with erratic movements after about 10 minutes, indicating stress. (B) In near-neutral water (pH 6.20), the fish remained calm with normal opercular activity. The comparison illustrates how acid stress alters respiratory behaviour and mucus production in fish. All photos were taken on 12 November 2025 during the same session and are not manipulated by any AI applications.

Acute acid exposure explains the patterns in Figure 4: low pH rapidly disrupts gill function by increasing epithelial permeability and disturbing acid–base and ion regulation, which forces compensatory ventilatory effort and produces visible mucus hypersecretion and erratic swimming (the stressed fish at pH 2.24) while near-neutral pH maintains normal opercular rhythm (pH 6.20). Classic and recent work shows that the fish gill is the dominant site for gas exchange, osmoregulation, and acid–base balance, so acid stress quickly manifests as respiratory distress and behavioural change [26]. At low pH, H^+ interferes with Ca^{2+} at the gill, elevates ionic permeability, and compromises Na^+ balance, mechanisms long documented for freshwater fishes [27, 28]. Regulatory agencies and contemporary syntheses likewise list increased mucus production, gill damage, and hyperexcitability as hallmark responses to pH departures from the optimal range [24]. Experimental observations across species confirm that extreme pH elicits hyperactivity, surface-oriented movements, elevated opercular rate, and excess mucus within minutes to hours, matching the outcomes we recorded [29, 30]. Together, these mechanisms account for the rapid divergence between treatments in our assay and underscore the pedagogical value of real-time, mechanism-anchored observation in ecotoxicology.

6. Students' reflections and interpretations

6.1 Discovery and curiosity

Dr. Tiamiyu described the practical session as inquisitive and purposeful. His reflection showed how firsthand observation of the benthic community nurtured genuine inquiry and transformed questions into investigations, a pattern consistent with transformative and emancipatory forms of experiential learning that grow through dialogue, patience, and reflection [1, 6, 14]. The practical thus bridged theory and field discovery in ways reported for narrative and team-based experiential designs [3].

6.2 Connecting theory to everyday life

Austin emphasized how the class allowed him to connect theory to real environments. Linking the small red worms near his home to those in the polluted drainage made pollution tolerance concrete and place-based, mirroring evidence that local, sensory cues deepen ecological understanding [4, 5]. The hands-on, blended approach "made the theory alive," aligning with interactive platform-supported experiential learning and the use of immediate natural resources to heighten curiosity and uptake [2, 31].

6.3 Childhood memory and scientific understanding

Tobias found meaning in seeing odonate larvae he collected as a child, now reframed through scientific inquiry. This continuity from curiosity to investigation echoes narrative accounts of experiential projects that scaffold reflective growth and professional identity [3, 16]. His fascination with the catfish assay under altered pH reflects how simple, visible stress responses can anchor concepts in physiology within blended, observation-rich activities [2].

6.4 Seeing life in polluted water

Fatihah described the experience as enlightening, realizing that worms, insects, and snails can thrive in degraded systems. Her insight resonates with frameworks that connect sensory attention to ecological resilience and that advocate learning with place as a living resource for concept formation [4, 31]. The fieldwork helped her read complex biological stories in everyday settings, consistent with integrative literacy approaches that join environmental context with active learning [32].

6.5 Method and imagination

Sridaran called the fieldwork a valuable learning experience. Gaining confidence with tools and observations while considering protocol refinement aligns with evidence that field learning builds employability-relevant capacities in measurement, problem solving, and reflection [16]. His shift from procedure to creative design also reflects student-centered pedagogies that cultivate ownership and sustained engagement in sustainability education [17].

6.6 Observation through controlled experimentation

Erra's reflection balanced enthusiasm with attentiveness. She highlighted learning to sample sediments and to run a ten-minute catfish assay at pH 2 and pH 6, noting clear behavioral responses. Such concise, well-scaffolded experiments exemplify blended experiential formats that make mechanisms visible and prompt cross-disciplinary dialogue among learners [2, 14]. Her comments also parallel findings from problem- and community-based training where authentic, bounded tasks elicit focus, confidence, and applied judgment [15], supported by inclusive, compassionate teaching practices that foreground belonging and engagement [33, 34].

7. Integration of student experiences

Read together, the student vignettes show that field-based education fosters multi-sensory engagement and collaborative sense-making. Students moved beyond taxonomic labels to embodied noticing: the texture of sediment, the odor of drainage, color gradients in the water, and rapid opercular beats in stressed fish. Such moments align with experiential designs that center perception and reflection as core to learning, including olfactory and tactile cues that are often neglected in formal instruction [4], and with urban field classrooms that make nearby environments legitimate sites of inquiry [5]. The iterative movement between looking, naming, and inferring also reflects emancipatory and transformative strands of experiential education that cultivate agency alongside understanding [1, 6].

Figures 1 and 2 clearly visualize this integration in action: students transition from field collectors to analysts, embodying the dual role of scientist and observer. Their dialogue at the bench mirrors practices recommended for blended and interactive experiential platforms that scaffold observation, comparison, and feedback [2]. The teamwork dimension resonates with narrative accounts of global and distributed experiential projects where roles, responsibilities, and reflective conversation amplify learning gains [3, 14]. As students connected procedures to community and professional relevance, their comments echoed findings from problem- and community-based environmental health training, in which authentic tasks strengthen motivation and applied judgment [15]. The broad pedagogical arc, that can link physical activity, environmental contexts, and ecological meaning, also sits comfortably within integrative frames that unite physical and environmental education to build literacies for action [32]. Finally, using local natural resources as learning media parallels evidence from rural STEAM cases that hands-on interaction with place enhances conceptual uptake and curiosity [31].

8. Mentor's synthesis and reflection

Figure 5 portrays the mentoring arc that framed the entire practical: a concise pre-briefing that set objectives, safety, and sampling logic, followed by real-time coaching at the microscope where field specimens were translated into identifiable taxa and ecological evidence. This rhythm includes clear intent, guided technique, and immediate interpretation, all turned routine tasks into meaningful inquiry. Students entered the drain with a mental model of what to look for, why sieving mattered, and how macrobenthos signal pollution; they left the bench able to connect morphology with tolerance and habitat quality. The mentor's prompts and clarifications made the session purposeful, ensuring that every step from scooping sediment to viewing gills and chaetae contributed to a coherent understanding of ecotoxicology in practice [35].

Figure 5 Briefing and explanation session conducted by the mentor before and during the macrobenthos practical class conducted on 12 November 2025. The left image shows the mentor providing an overview of the sampling objectives and safety procedures, while the right image captures the microscopic examination of specimens in the laboratory. This mentorship approach transformed the practical into a purposeful and reflective learning experience, guiding students to connect theoretical foundations with real biological observations. All photos were taken on during the same session and are not manipulated by any AI applications.

From the mentor's vantage, smiles, focused gazes, and peer explanations were not peripheral; they were data of learning. Such affective and interpersonal signals are consistent with compassionate, student-centered pedagogies that strengthen inclusion and deepen cognitive engagement in environmental studies and sciences [17, 33]. The practical session's design namely short cycles of field observation, bench verification, and collective interpretation that supports employability-relevant capacities reported for field learning in Geography, Earth, and Environmental Sciences, including careful measurement, collaborative problem-solving, and reflective communication [16].

Across the activities, students' confidence grew as drains, worms, and pH readings became evidence rather than curiosities. This growth echoes calls to practice diversity, equity, inclusion, and justice in environmental curricula, where belonging and voice are treated as conditions for rigorous inquiry [33, 34]. The final close-ups in Figure 3; an odonate larva beside a ruler, all symbolize the union of wonder with measurement: every millimeter invites a question, every question a method. That synthesis is the promise of experiential ecotoxicology, where sensory attention, collaborative dialogue, and careful technique converge to form durable understanding [1, 2, 6].

9. Conclusion

The synthesis of reflections from all students highlights that learning is not confined to intellectual comprehension but also emotional resonance. Their voices show how hands-on ecotoxicology transforms abstract concepts into living understanding. Through sediment, fish, and benthic organisms, they encountered not only science but also themselves as learners. For me as their mentor, their excitement and curiosity reaffirmed that the purpose of teaching is not simply to inform but to inspire. When students engage with science through their senses, they discover that even polluted waters can reflect the purity of learning.

Author Contributions

Conceptualization, C.K.Y., N.A.B. and W.M.S.; methodology, C.K.Y.; software, N.A.B.; validation, C.K.Y. and W.M.S.; formal analysis, E.N.B., N.F.A.F., and S.M.; investigation, V-G., T.S., T.Y.A.H., A.R., M.I.M.H., M.M.L., and M.A.S.; resources, N.A.B.; data curation, C.K.Y.; writing—original draft preparation, C.K.Y.; writing—review and editing, W.M.S. and M.A.T.; visualization, E.I.H. and H.R.A.Y.; supervision, C.K.Y.; project administration, C.K.Y. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

No conflicts of interest exist.

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